# Chapter 5
# Horizontal Control Survey Techniques

## 5-1. General

This chapter outlines procedures to follow for horizontal control surveys. The material presented is not meant to be rigid methodology that cannot be tailored for a particular application. The mandatory classifications and standards portions must be followed, while the recommendations should be followed whenever possible. Refer to EM 1110-1-1003 for more information on GPS survey techniques, as well as any of the applicable references listed in Appendix A for further guidance on information not covered in this chapter.

**NOTE**: The accuracy of control surveying measurements should be consistent with the purpose of the survey. It is important to remember that the best survey is the one that provides the data at the required accuracy levels without wasting manpower, time, and money.

## 5-2. Horizontal Control Surveys

Horizontal control surveys are done to establish primary or secondary horizontal control points. The procedures to establish the control are traverse, triangulation, and/or trilateration. The preferred method for establishing horizontal control is to use a traverse and GPS survey techniques. When conventional horizontal control survey techniques are used, the preferred instrument is a total station; and if such equipment is not available, a theodolite and electronic distance measuring equipment (EDM) are often used. Always keep the project requirements paramount (e.g., accuracy, time, money, manpower, etc.) when determining what survey procedures to follow and the equipment to be used.

## 5-3. Primary Horizontal Control

Primary horizontal control is established at accuracies where practicable to meet the requirements of the application, typically at Third-Order Class I or better. Primary horizontal control is established to serve as a basic framework for large mapping projects, to establish new horizontal control in a remote area, or to further densify existing horizontal control in an area.

*a.* The minimum instrument requirements for the establishment of primary control shall be: a repeating theodolite with an optical micrometer with a least count resolution of six seconds (i.e., 6") or better; or a directional theodolite with an optical micrometer with a least count resolution of one second (i.e., 1") and an EDM capable of a resolution of 1:10,000; or a total station or other instrument having capabilities comparable to or better than any of the instruments just detailed.

*b.* Primary horizontal control points not permanently monumented in accordance with criteria and guidance established in EM 1110-1-1002 should meet the following minimum standards:

(1) Primary horizontal control points shall be marked with semipermanent-type markers (e.g., rebar, railroad spikes, large spikes).

(2) Primary horizontal control points shall be placed either flush with the existing ground level or buried a minimum of one tenth of a foot below the surface.

(3) Each primary control point shall be referenced by a minimum of two points to aid in future recovery of that point. For this reference, well defined natural or man-made objects may be used. The reference point(s) can be either set or existing and should be within 100 feet of the control point.

(4) A sketch shall be placed in a standard field book. The sketch at a minimum will show the relative location of each control point to the reference points and major physical features within 100 feet of the point.

(5) If concrete monuments are required, they will be established prior to the accomplishment of any horizontal survey work. These monuments will be established in accordance with EM 1110-1-1002.

*c.* Primary horizontal control points shall be occupied by an electronic total station, a theodolite and EDM, or comparable equipment. Establishing primary control points by one angle and one distance will not be permitted.

*d.* Distance measurements for primary horizontal control points shall be accomplished with a total station, an EDM, or other comparable equipment capable of obtaining an accuracy of 1:10,000.

*e.* When an EDM is used, a minimum of two readings shall be taken at each setup and recorded in a standard field book. The leveled height of the instrument and the height of the reflector shall be measured carefully to within 0.02 foot and recorded in the field book. Each slope distance shall be reduced to a horizontal distance using either reciprocal vertical angle observations or from the elevation of each point obtained using differential leveling.

*f.* All total stations, EDMs, and prisms used for primary control work shall be serviced regularly and checked frequently over lines of known length. Calibration should be done at least annually.

*g.* If a repeating theodolite (e.g., Wild T1) is used for the horizontal angles, the instrument will be pointed at the backsight station with the telescope in a direct reading position, and the horizontal vernier set to zero degrees. All angles shall then be turned to the right, and the first angle recorded in a field book. The angle shall be repeated a minimum of four times (i.e., two sets) by alternating the telescope and pointing in the direct and inverted positions. The last angle will also be recorded in the field book. If the first angle deviates more than five seconds (i.e., 5") from the result of the last angle divided by four, the process shall be repeated until the deviation is less than or equal to five seconds. Multiples of 360 degrees may need to be added to the last angle before averaging. The horizon shall be closed by repeating this process for all of the sights to be observed from that location. The foresight for the last observation shall be the same as the backsight for the first observation. If the sum of all the angles turned at any station deviates more than ten seconds (i.e., 10") from 360 degrees, the angles shall be turned again until the summation is within this tolerance.

*h.* If a directional theodolite (e.g., Wild T2, Wild T3) is used for the horizontal angles, the instrument shall be pointed at the backsight station with the telescope in a direct reading position and the horizontal vernier set to within ten seconds (i.e., 10") of zero degrees. The vernier shall be brought into coincidence and the angle read and recorded in the field book. The angles shall then be turned to each foresight in a clockwise direction, and the angles read and recorded in a field book. This process will continue in a clockwise direction and shall include all sights to be observed from that station. The telescope shall then be inverted and the process repeated in reverse order, except the vernier is not to be reset, but will be read where it was originally set. The actual angles between stations may then be computed by differencing the direct and reverse readings. This process shall be repeated three times for a total of three data set collections.

*i.* Regardless of the theodolite used, at least once a year and whenever the difference between direct and reverse reading of any theodolite deviates more than 30 seconds from 180 degrees, the instrument should be adjusted for collimation error. Readjustment of the cross hairs and the level bubble should be done whenever their misadjustments affect the instrument reading by more than the least count of the vernier of the theodolite.

*j.* If a total station is used for the horizontal angles, the same procedure shall be followed as detailed in the preceding paragraphs *g* and *h*, depending on the type of total station used. When using high precision total stations, only half as many readings are generally required (two data set collections).

*k.* To reduce slope distances to horizontal, a vertical angle observation must be obtained from each end of each line being measured. The vertical angles shall be read in both the direct and inverted scope positions and adjusted. If the elevations for the point on each end of the line being measured are obtained by differential levels, this vertical angle requirement is not necessary.

*l.* All targets established for backsights and foresights shall be set directly over the point to be measured to. Target sights may be a reflector or other type of target set in a tribrach, a line rod plumbed over the point in a tripod, or guyed in place from at least three positions. Artificial sights (e.g., a tree on the hill behind the point) or hand-held sights (e.g., line rod or plumb bob string) will not be used to set primary control targets.

## 5-4. Secondary Horizontal Control

Secondary horizontal control is established at accuracies where practicable to meet the requirements of the application, generally at Third Order Class II or lower. Secondary horizontal control typically is established to determine the location of structure sections, cross sections, or topographic surface, or to pre-mark requirements for small- to medium-scale photogrammetric mapping.

*a.* Secondary horizontal control requirements are identical to those described for primary horizontal control with the following exceptions.

(1) Monumentation. It is not required for secondary horizontal control points to have two reference points.

(2) Occupation. Secondary horizontal control points can be established by one angle and one distance.

(3) When a total station or EDM is used, a minimum of two readings shall be taken at each setup and recorded in a standard field book.

(4) If a repeating theodolite is used for the horizontal angles, the angle measurement shall be repeated a minimum of two times by alternating the telescope and pointing in the direct and inverted positions.

(5) If a directional theodolite is used for the horizontal angles, the process (described for primary control) shall be repeated two times for a total of two data set collections.

## 5-5. Traverse

A traverse is defined as the measurement of the lengths and directions of a series of straight lines connecting a series of points on the earth. The points connected by the lines of traverse are known as traverse stations. The measurements of the lengths and directions are used to compute the relative horizontal positions of these stations. In the past, the traverse distances were determined by indirect measurement or taping and these traverses were used primarily as supplementary control to area triangulation networks. However, with the advent of total stations and EDM's, the traverse is now frequently used for basic area control surveys. In addition to the observation of horizontal directions between traverse stations, the elevation of the stations must be determined by either direct or trigonometric leveling. Astronomic observations must be made along a traverse at prescribed intervals to control the azimuth of the traverse and sometimes to determine the deviation of the vertical (plumb line). The interval and type of astronomic observation will depend upon the order of accuracy required and the traverse methods used.

*a. Traverse types.* There are two types of traverses, the closed and the open.

(1) Closed traverse. A traverse that starts and terminates at a station of known position is called a closed traverse. The order of accuracy of a closed traverse depends upon the accuracy of the starting and ending known positions and the survey methods used in the field measurements. There are two types of closed traverses.

(a) Loop traverse. A loop traverse starts on a station of known position and terminates on the same station. A loop traverse will detect blunders and accidental errors, but will not disclose systematic errors or inaccuracies in the starting information.

(b) Connecting traverse. A connecting traverse starts on a station of known position and terminates on a different station of known position. When using this type of traverse the systematic errors and position inaccuracies can be detected and eliminated along with blunders and accidental errors. This type of traverse is always preferred over a loop traverse when a choice exists.

(2) Open traverse. The open traverse starts on a station of known position and terminates on an unknown position. In this type of traverse, there are no checks to determine blunders, accidental errors, or systematic errors that may occur in the measurements. The open traverse is very seldom used in topographic surveying because a loop traverse can usually be accomplished with little added expense or effort. If conditions require it, a picture point may be located by a side shot (open traverse) if project specifications permit.

*b. Guidelines.* The following minimum guidelines should be followed when performing traverse procedures:

(1) Origin. All traverses will originate from and tie into an existing control line of equal or higher accuracy. No traverse will be stubbed off or dead-ended (e.g. radial or spur spots) except by specific instructions from the appropriate authority.

(a) Astronomic observation. Under some conditions it may not be possible to start or terminate on stations of known position and/or azimuth. In these cases, an astronomic observation for position and/or azimuth must be accomplished. For Third Order, only an astronomic azimuth is required at intervals along the traverse and at abrupt changes in direction of the traverse. Placement of these astronomic stations is governed by the order of accuracy required.

(b) Route and/or location. Generally, where to start a traverse and tie it in are predetermined. Where practicable, always show additional ties to other lines if the traverse course being followed approaches other lines or triangulation points. The advantage of additional ties is the possibility of isolating an error even if it is not the intention to adjust the traverse into the extra ties. The specific route of a new traverse shall be selected with care, keeping in mind its primary purpose and the possibility of its future use. Angle points should be set in protected locations if possible. Examples of protected locations include at fence lines, under communication or power lines near poles, or any permanent concrete structure. It may be necessary to set critical points underground. If so, reference the point relative to permanent features by a sketch, as buried points are often difficult to recover at future dates.

(2) Accuracy. Traverses are performed under four general orders of accuracy: First, Second, Third, or Construction Layout/Fourth Order. First-Order traverse work requires a high degree of accuracy, instruments, and methods of precision, and therefore typically is not done in the USACE. The order of accuracy for any traverse is determined by the equipment and methods used in the traverse measurements, by the accuracy attained, and by the accuracy of the starting and terminating stations of the traverse. The point closure standards in Table 3-1 must be met for the appropriate accuracy classification to be achieved. Table 5-1 lists general guidelines for the number of angle points between bearing checks and bearing discrepancies per angle point necessary to achieve the desired accuracy. A disadvantage of the traverse is the lack of field or computation checks on the accuracy until the traverse is connected to previously established traverse or triangulation networks of the appropriate order of accuracy.

**Table 5-1**
**General Traverse Requirements for Horizontal Control Surveys**

| | USACE Classification | |
|---|---|---|
| Requirement | Second-Order | Third-Order |
| Number of angle points or distance between bearing checks | 10 to 20 angle points | 20 to 40 angle points but not > than 5 miles |
| Bearing discrepancy per angle point (not to exceed) | 2.0 seconds | 5.0 seconds |

## 5-6. Various Forms of Traverse

Although there are various forms of traverses, they all have very basic and common methods of operation. The main differences between them is: the accuracy with which they are run, the different style of field notes required, and equipment used. Figure 5-1 shows some survey equipment used for traverse work. The field procedures are dictated by the type of traverse to be done. Even though there are equipment differences and level of accuracies achievable by the type of traverse to be done, the procedures for each can be generalized.

*a. Control traverses.* Control traverses typically are run for use in connection with all future surveys to be

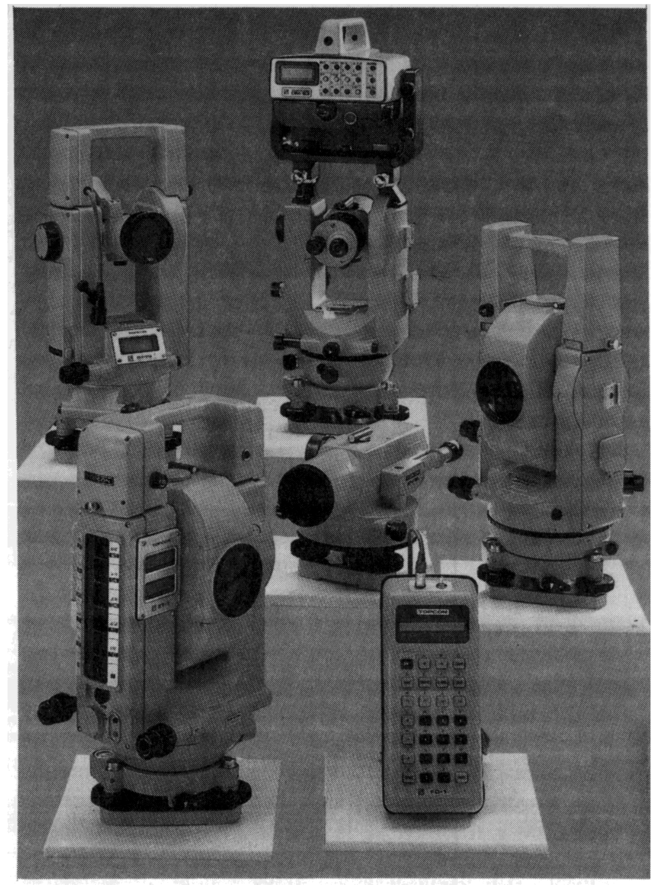

**Figure 5-1. Typical survey equipment used in traverse and horizontal control work**

made in the area of consideration. They may be of First-, Second-, or Third-Order accuracy, depending on requirements.

(1) Most project requirements are satisfied with Second- or Third-Order accuracies. It is very unusual to have requirements in the USACE for First-Order traverse work. A Second-Order traverse requires special procedures both in the field and in the office to achieve the required accuracies for a particular project. A Second-Order traverse generally is necessary for special jobs or in areas where there is not sufficient triangulation control. Often, a secondary triangulation net is established instead of a traverse; but in flat areas, it is sometimes difficult to establish much control by triangulation because of sighting limitations, therefore it is advisable to run a Second-Order traverse, establishing permanent points at intervals of one mile or less.

(2) For a Second-Order traverse, the first step is to determine a good route. Start at a known point, preferably an NGS or USC&GS triangulation point. Plan the traverse to follow a route that will be centered as much on the work as possible, yet through areas that will not be bothered by construction, traffic, or other forms of congestion. The route should check into other known points as often as practicable. Depending on the application, examples of good traverse routes include ones along the edge of a road or the banks of a main river. After determining the route, it is best to next set permanent monuments (e.g., tee bars, brass caps, concrete, or some other suitable monument) at each angle point and any intermediate points desired. Refer to EM 1110-1-1002 for further guidance on survey markers and monumentation. Make sure there is a clear line of sight from angle point to angle point. Determine a numbering or naming system and mark all points at the time of setting.

(3) EDM or total station operation is less labor intensive, generally more productive, and provides as good as or better results than most conventional surveying methods. Manufacturer instructions for operation of the EDM or total station should be followed to determine distances between monuments and posts in the line.

(4) When using an EDM or total station, a minimum of two readings will be done before moving to the next post. All readings should agree within 0.001 foot with the original reading.

(5) Determination of angles should be done as soon as practicable after distance determination. Most total stations combine these two determinations (i.e., the distance and angle determinations). Special care should be taken with the type of sights used in the angle determination. Use as small a sight as possible given the requirements for clear vision of the target. The shorter the sight, the more important this consideration becomes. Fixed rigid sights should be used, not hand-held ones. If weather is especially hot or humid, early mornings or late evenings should be reserved for angle determination. Second-Order results generally do not require using lights or working at night, except under the most unusual of circumstances. It is desirable to use a directional theodolite or total station for all angle determinations. It is best to turn no less than three sets of angles, direct to right, if possible. Adequate results can be obtained with fewer angles if the best of equipment is used, but a few extra angles takes very little time compared with setting up instruments, traveling to the job, etc.. If results look slightly weak after turning the minimum angles, add extra angles, and consider closing to the horizon. All angle notes should be completely reduced and mean angle figured in the field and recorded along with the sketch. All adjustments should be made in the office. At the time of angle determinations, a sketch of the monument location should be made and a detailed description on how to find it written. This information will be used for making subsequent record of the survey monument.

*b. Right-of-way traverse.* A right-of-way traverse typically is a Third-Order traverse, starting and ending on known points. This type of traverse is usually run with a transit and tape, EDM, or total station. The style of notes is similar to most traverses with the only difference being the type of detail shown. Fences are of particular importance in determining right-of-way limits, especially when working in an area not monumented. Notes for right-of-way traverses should be especially clear and complete for many times this type of traverse is the basis for law suits or court hearings regarding true property corners. If a search for a corner is made and nothing is found, a statement should be written in the field book to this effect. Be sure before getting to the field to know where to expect to find the corners. This information generally is available from recorded maps, the word of property owners, etc.

*c. Stadia traverse.* This type of traverse is not used for day-to-day operations to establish horizontal control. A stadia traverse can be used for establishment of rough (Third-Order or lower) horizontal control. Uses of stadia traverses include rough- or reconnaissance-type surveys, checking on another traverse for errors, and control for a map being made by stadia methods on a very large scale. A stadia traverse typically is run along a route that will best suit the needs of the survey. The stadia points or stadia angle points will be set at locations that will best fulfill the purpose of the traverse and if possible will be set in protected locations for future use.

*d. Topography traverse.* This type of traverse is usually Third-Order or close to it and can be used for horizontal control in some instances. Its intended purpose is for controlling the mapping of an area previously determined. Because of this, it usually is necessary to determine elevations over the line prior to mapping. Some surveyors prefer to carry levels along with a transit survey, but this generally does not always provide results accurate enough for project requirements. Refer to EM 1110-1-1005 for guidance on topographic surveying.

*e. Deflection traverse.* A deflection traverse is used to indicate the way in which angles are turned with the transit or other instrument. This term usually applies to

Third-Order traverses with the only exception being compass traverses. A deflection angle is an angle that is measured right or left of the back tangent produced ahead of the instrument. The angle is measured by sighting the back tangent and plunging the instrument before turning to forward tangent. Accuracy is obtained by repeating this procedure using standard operating procedures for transit work. This method is especially good when office computations use a bearing and not an azimuth system.

*f. Compass traverse.* This type of traverse is exactly what its name implies: it is a traverse where the direction of the line is measured by a compass. In a compass traverse, no angles are turned. Distances are usually measured by stadia or paced if work is very rough. When using a compass to do a traverse, pacing is all it takes to determine distances comparable to the accuracies offered by the compass.

*g. Azimuth traverse.* Like a bearing, an azimuth denotes direction. Bearings break the directions into four quadrants, while an azimuth measures direction from one point. This point can be true North, South, or on some other base. Azimuth angles should always be turned to the right. This turning practice is particularly important for many directional instruments only read or turn to the right (e.g., most Wild instruments).

## 5-7. Traverse Classifications and Specifications

Traverses can be classified according to the type of instruments used to do them. All horizontal control surveys conducted by traverse will be classified based on the horizontal closure standards given in Table 3-1. Table 5-2 lists specific traverse requirements necessary to meet Second- and Third-Order type accuracies.

*a. Second-Order.* Second-Order traverse is used extensively for subdividing an area between First- and Second-Order triangulation and First-Order traverse. Second-Order traverse must originate and terminate on existing first or second order control that has been previously adjusted.

*b. Third-Order.* Third-Order traverse is normally used for detailed topographic mapping. Third-Order traverse must start and close on existing control stations of Third- or higher order accuracy.

*c. Lower order.* Traverses of lower than Third-Order are used for controlling points when a relatively large error in position is permissible. However, with the advent of new equipment, very little is saved either in time or money by using lower order traverse. The use of Third-Order methods should be carefully considered, even though the points are not to be monumented permanently. The map compilation requirement usually is that a horizontal control picture point for 1:50,000 mapping shall be located to within 6 m of its true relationship to the basic control. For 1:25,000 mapping the requirement is usually to within 3 m. The allowable errors permit accuracies to vary from generally 1 part in 500 to 1 part in 5,000, depending on the distance the lower order traverse must travel, the type of control at the start of the traverse, the desired accuracy of the control point and the methods and equipment used in the traverse.

**Table 5-2**
**Traverse Requirements**

| Requirement | Second-Order | Third-Order |
|---|---|---|
| | Horizontal Directions or Angles | |
| Instrument | 0.2" or 1.0" | 1.0" |
| Number of observations | 6 - 8 | 2 - 4 |
| Rejection limit from mean | 4 or 5" | 5" |
| | Number of Azimuth | |
| Courses between azimuth checks not to exceed for: | | |
| Tape | 25 | 35 - 50 |
| Electronic | 12 - 16 | 25 |
| | Azimuth Closure | |
| Probable error | 2.0" | 5.0" |
| | Azimuth Closure at | |
| Azimuth checkpoint not to exceed | 10"*$N^{0.5}$ or 3" per station | 15"*$N^{0.5}$ or 5" per station |

Note: *N* is the number of stations carrying azimuth

**Note:** For Second-Order, the use of the traverse will dictate the type. For Third-Order, an astronomic azimuth station is sufficient. When two expressions are given, the formula which gives the smallest permissible value should be used.

## 5-8. Triangulation and Trilateration

Triangulation and trilateration may be used to establish horizontal control in areas where it is not practical to use other methods. Unless otherwise directed, horizontal control established by triangulation and trilateration will be at least Third-Order accuracy for most applications. As a general policy, the following minimum guidelines should be followed when performing triangulation and/or trilateration procedures:

*a. Origin.* When practicable, all triangulation and trilateration nets will originate from and tie in to existing control of equal or higher accuracy than the work to be performed. An exception to this policy would be when performing a triangulation or trilateration across a river or some obstacle as part of a chained traverse. In this case, a local baseline should be set.

*b. Accuracy.* The point closure standards in Table 3-1 must be met for the appropriate accuracy classification to be achieved. If project requirements are First-Order, refer to the FGCC/FCCS Standards and Specifications for Geodetic Control Networks (FGCS 1984).

*c. Triangulation and trilateration methods.* Triangulation and trilateration methods are similar in basic principle. A triangulation system consists of a series of joined or overlapping triangles in which an occasional line is measured and the balance of the sides are calculated from angles measured at the vertices of the triangle. A trilateration system also consists of a series of joined or overlapped triangles, but contrary to a triangulated system, a trilaterated system measures the lengths of all the sides of the triangles and only enough angles and directions to establish azimuth. Unfortunately, the nature of trilateration is such that only procedural guides are available to the field parties; they can only adhere to project instructions and specifics which should permit later computations to show the desired accuracy.

## 5-9. Bearing and Azimuth Determination

Bearing and azimuth determination are typically done as the basis for horizontal control surveys.

*a. Bearing types.* The bearing of a line is the direction of the line with respect to a given meridian. A bearing is indicated by the quadrant in which the line falls and the acute angle which the line makes with the meridian in that quadrant. The reference meridian may be either "true," magnetic, or assumed, while the bearings likewise also are "true," magnetic, or assumed.

(1) Observed bearings are those for which the actual bearing angles are directly obtained by survey field work, while calculated bearings are those for which the bearing angles are indirectly obtained by calculations.

(2) A true bearing is one whose reference meridian is a true meridian of the earth -- a meridian passing through the earth's poles and the projection of which passes through the celestial pole. The earth's poles are the geographic north and south poles. The celestial pole is geodetic north, the position of which is defined by its angular relationship to the North Star or Polaris. For general surveying purposes, it is assumed that for any given point on earth, true meridian is always the same, ensuring that any directions referred to the true meridian will remain the same regardless of time.

(3) A magnetic bearing is one whose reference meridian is the direction taken by a freely suspended magnetic needle (i.e., a compass). The magnetic poles are at some distance from the true poles, so the magnetic meridian typically is not parallel to the true meridian. The location of the magnetic poles is constantly changing, therefore the magnetic bearing between two points is not constant over time. Thus, magnetic bearings should only be used for reconnaissance work, rough surveys, and real-estate surveys.

(4) The angle between a true meridian and a magnetic meridian at the same point is called its magnetic declination. A line on the earth's surface which has the same magnetic declination throughout its length is called an "isogonic" line, while the line where magnetic north and a true meridian coincide is called an "agonic" line.

(5) An assumed bearing is a bearing whose prime meridian is assumed. In some cases, the relationship between an assumed bearing and the true meridian is given a definite calculable relationship. This is the case with most state plane grid coordinate systems used to make maps.

*b. Bearing determination guidelines.* All bearings used for engineering applications will be described by degrees, minutes, and seconds in the direction in which the line is progressing. The accuracy of its calculation is dependent on the exact measurements of distances and bearings. Also, the bearing will state first its primary direction, north or south, and next the angle east or west. For example, a line can be described as heading north and deflected so many degrees east or west. Alternatively, a line also can be described as heading south and deflected so many degrees east or west. A bearing will never be listed with a value over 90˚ (i.e., the bearing value always will be between 0˚ and 90˚).

*c. Azimuth types.* The azimuth of a line is its direction as given by the angle between the meridian and the line, measured in a clockwise direction. Just like bearings, azimuths can be either "true," magnetic, or assumed, depending on the meridian to which they are referenced. Azimuths can be indicated from either the south point or the north point of a meridian.

(1) Assumed azimuths are often used for making maps and performing traverses. Typically, for USACE maps and traverse work, the angles (i.e., the azimuths) are determined in a clockwise direction from an assumed meridian. Assumed azimuths are sometimes referred to as “localized grid azimuths.”

(2) Azimuths, just like bearings, can be either observed or calculated. An observed azimuth is simply one which is read by using electronic instrumentation, transit, or compass in the field. Calculated azimuths are those obtained by computation. For example, a calculated azimuth may consist of adding to or subtracting field observed angles from known bearings or azimuths to determine other bearings or azimuths.

*d. Azimuth determination guidelines.* An azimuth will be determined as a line with a clockwise angle from the north or south end of a true or assumed meridian. The accuracy of its calculation is dependent on the exact measurement of distances and bearings. For traverse work using angle points, the requirements in Table 5-1 will be followed.

## 5-10. Astronomic Observation Requirements

*a. Azimuth.* In order to control the direction of a traverse, an astronomic azimuth must be observed at specified intervals and abrupt changes of direction of the traverse. The specified intervals and the maximum deflection of the traverse will depend upon the accuracy of the traverse. The observation of an astronomic azimuth can be made by the hour angle method or altitude method. The method used will depend upon your location on earth and/or the order of accuracy required. A set of positions for an azimuth observation consists of half the required positions being observed using the rear station as an initial and half using the forward station as an initial. Using rear station, turn clockwise to forward station then to star, reverse telescope on star, then forward station and back to rear station. Using forward station, turn clockwise to rear station then to star, reverse telescope on star, then rear station and back to forward station. The number of position repetitions will depend upon the order of accuracy required.

*b. Position.* For Second-Order traverse the observation of position for a Laplace azimuth will depend upon the use of the traverse, and the project instructions typically will specify when an astronomic position is required. For Second- and Third-Order, it is often necessary to observe astronomic positions to obtain the starting and terminating azimuth data.

## 5-11. Three-Point Resection

Three-point resection is a form of triangulation. Three-point resection will be used in areas where existing control points cannot be occupied or when the work does not warrant the time and cost of occupying each station. Triangulation of this type will be considered Fourth-Order, although Third-Order accuracy can be obtained if a strong triangular figure is used and the angles are accurately measured. The following minimum guidelines should be followed when performing a three-point resection:

*a. Location.* Points for observation should be selected so as to give strong geometric figures.

*b. Observation.* If it is possible to sight more than three control points, the extra points should be included in the figure so that the computed position can be verified.

(1) When it is possible to occupy one of the control stations, it should be done as this added information will serve as a check on the computations and increase the accuracy because its position can also then be computed directly and checked by three-point computation. Occupation of a control station is especially important as it serves as a control of the bearing or direction of a line if a traverse were to originate from this same point.

(2) The interior and exterior angles shall be observed and recorded. The sum of these angles shall not vary by more than 3 seconds per angle from 360 degrees.

(3) Each angle will be turned not less than 2 times, but preferably 4 times, 2 direct and 2 inverted. Turn all angles to the right.

## 5-12. GPS Surveying

Establishing or densifying horizontal control with differential carrier-phase based GPS is often cost-effective, faster, more accurate, and more reliable than most conventional methods. The quality control statistics and large number of redundant measurements in GPS networks help to ensure viable results. Differential carrier-phase based GPS is particularly attractive for horizontal control surveying as compared with conventional surveys because intervisibility is not required between adjacent stations and GPS equipment is not limited by optics for its range of operations as are most conventional survey instruments. Horizontal control established with differential carrier-phase based GPS (in accordance with guidelines detailed in EM 1110-1-1003) will be of sufficient quality for most applications.